Effects of high-intensity power-frequency electric fields on implanted modern multiprogrammable cardiac pacemakers[1]

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Summary: The effect on an implanted, multiprogrammable pacemaker of power-frequency (50 Hz) electric fields up to an intensity (unperturbed value measured at 1.7 m) of 20 kV/m were assessed in ten paced patients. Radiotelemetric monitoring of the electrocardiogram allowed supervision of the electrocardiogram throughout exposure to the alternating electric field. Displacement body currents of up to 300 μA were achieved depending on the position and height of the patient. None of the pacemakers was inhibited, triggered or reverted to fixed rate operation during the exposure. The programmable functions, programmability or output characteristics were not affected. Small changes in cardiac rate and rhythm elicited the correct pacemaker responses. Unlike earlier models of pacemaker, this modern implanted pacemaker, which represents 'the state of the art', is not affected by 50 Hz electric fields likely to be encountered when standing underneath power lines.

Introduction

Electric fields associated with high-tension cables may constitute an environmental hazard to patients with cardiac pacemakers. Current leaking to earth via the resistive tissues of the body may induce an alternating voltage across the pacemaker electrodes. Previous 'bench' studies have suggested that such electric interference may cause pacemaker function to revert temporarily to the asynchronous or insensitive mode (Smyth *et al.* 1974, Zalewski 1975). Animal experiments and theoretical considerations suggest that such electric fields are more likely to interfere with pacemakers of 'unipolar' configuration (Bridges & Frazier 1979).

This report is concerned with the effect of 50 Hz electric fields of up to 20 kV/m, during and after exposure, on the function of modern, unipolar, multiprogrammable pacemakers implanted in human subjects.

Patients and methods

Ten volunteer patients, each fitted with a Medtronic 5985 multiprogrammable (Spectrax) cardiac pacemaker, comprised the study group. The Spectrax pacemaker was chosen because it is unipolar and adjustable to a high sensitivity (1.25 mV); it is also sufficiently versatile to allow the changes of pacing rate and mode necessary for this study (Medtronic, c/o Simonsen & Weel Ltd, Ruxley Corner, Sidcup, Kent). Clinical and pacing details of the patients are provided in Table 1. In every case it was established that an adequate rhythm escaped when

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Table 1. Clinical and pacing data of patients

Patient	Sex	Age	Duration of implantation (months)	Site of pacemaker box	Electrode position	Heart disease
DB	F	79	9	Pectoral (L)	R atrium	Tachy-Brady syndrome
JH	M	62	5	Pectoral (R)	R atrium	Sinus arrest
SJ	M	74	3	Pectoral (L)	R ventricle	Syncope, RBBB
RJ	M	52	6	Pectoral (L)	R ventricle	AF and bradycardia
HF	M	60	6	Abdominal	Epicardial	2:1 AV block
HR	M	62	4	Pectoral (L)	R ventricle	Intermittent AV block
WS	M	67	4	Pectoral (L)	R ventricle	SSS
JD	M	50	2	Pectoral (L)	R ventricle	Post MI heart block
DK	F	72	4	Pectoral (L)	R ventricle	SSS
ML	M	68	4	Pectoral (L)	R ventricle	SSS

AF=atrial fibrillation, AV=atrioventricular, L=Left, MI=myocardial infarction, R=right, RBBB=right bundle branch block, SSS=sick sinus syndrome

the pacemaker was inactivated (by chest wall stimulation) and that competitive rhythms induced by magnet application, interference signals or 'program' adjustments were not obviously dangerous. Each patient provided written and informed consent.

Pre-exposure pacemaker evaluation: A formal pacemaker check was performed using a Vitatron Medical MAP1 analyser (Vitatron UK Ltd, Boyn Valley Road, Maidenhead, Berks). Stimulus pulse width, stimulus to stimulus interval and leading edge stimulus voltage were conventionally assessed with the patient in a semi-recumbent position. Utilizing the Medtronic 9701 programmer, a representative range of pacing rates and stimulus intervals were programmed.

Pacing function during exposure: The electrocardiogram (ECG) was monitored continuously by means of an aluminium foil-wrapped Hewlett-Packard 78100A telemetry transmitter

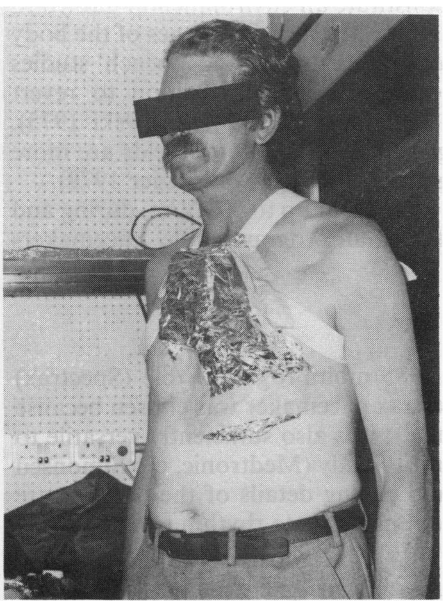

Figure 1. Patient with an aluminium foil-wrapped Hewlett-Packard telemetry transmitter

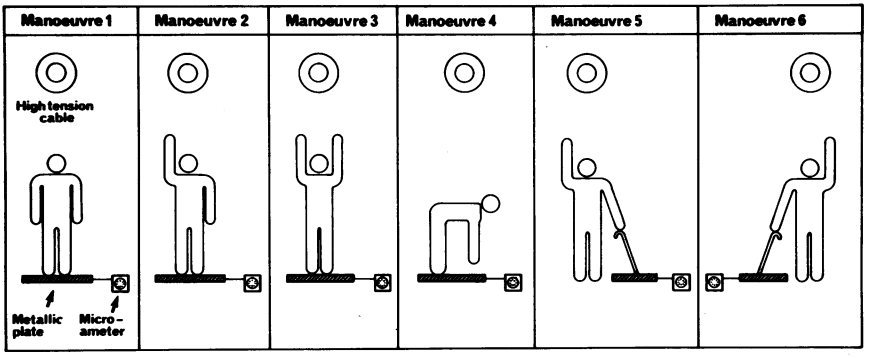

Figure 2. Diagrammatic representation of the six manoeuvres used for each test sequence

(Hewlett-Packard, Winnersh, Wokingham, Berks) attached by short leads to skin electrodes (Figure 1), as described in detail by Meldrum *et al.* (1982). The telemetry apparatus is a licensed system operating at 450 MHz. When applied, the transmitter did not noticeably affect pacemaker function. The ECG was recorded on a conventional oscilloscope connected to a hot pen writer.

The pacemaker was programmed to the highest available sensitivity, i.e. 1.25 mV of a 40 ms (25 Hz) sine^2 wave (haversine) and the pacing rate was adjusted initially to a value higher than, and less than, the natural heart rate. The demand mode was selected for the majority of the tests. In one patient the triggered mode was also evaluated. In four patients, rate hysteresis was adjusted to 40 beats/min. Exposures were carried out in the high voltage test bay at the Central Electricity Research Laboratories. Patients stood in the vertical electric field directly under a high voltage electrode, which was suspended approximately 6 metres above the floor.

The following manoeuvres were made by each patient during the exposure (Figure 2):

(1) Patient standing in stockinged feet, upright on an 18 inch (45.7 cm) square aluminium plate.
(2) Similar to (1) above with the left arm raised.
(3) Similar to (1) above with both arms raised.
(4) Standing bent over on the aluminium plate.
(5) Standing with the right arm raised on an isolated rubber mat and touching the aluminium plate with a conducting stick held in the left hand.
(6) Similar to (5) but with the arms reversed.

The electric field was adjusted to values between 1 and 20 kV/m (unperturbed values as measured at 1.7 m above the ground). The current passing through the body was measured by means of a microammeter connected between the aluminium plate and the ground. Exposure time during each manoeuvre ranged from 15–30 seconds.

Post-exposure pacemaker evaluation: The pre-exposure pacemaker check was repeated after the completion of the exposure protocol.

Results

Corporeal current: In this study the electric field induced a corporeal current which ranged from 10–318 μA. The measured current depended on the intensity of the field, the height of the patient (i.e. the distance between the patient and the field source) and the position of the patient (Figure 3).

Spontaneous cardiac rhythm: An increase in the heart rate (usually less than 10 beats/min) was observed in 4 patients. Very occasional ventricular ectopic beats were observed in 3 patients. No major disturbances in the heart rhythm were noticed in any patient during an average exposure time of 20 minutes.

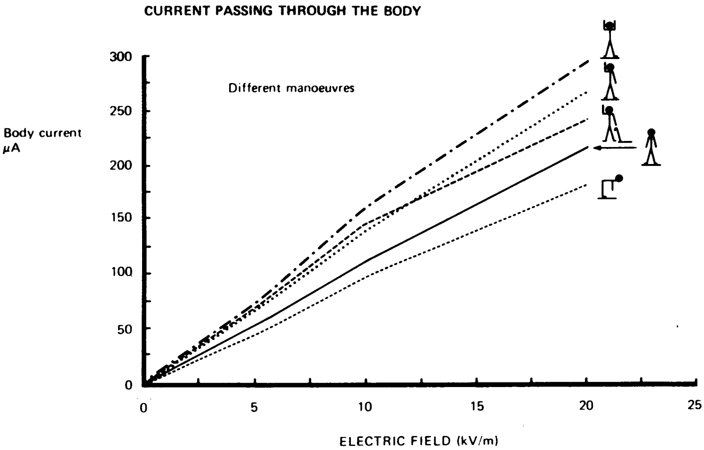

Figure 3. Body current plotted against field strength for five (1 5 in Figure 2) of the six manoeuvres, demonstrating that body current is proportional to field strength and that larger body currents are produced in the upright posture, especially when the arms are raised

Pacemaker function during exposure: When the pacemakers were set to rates less than the natural rhythm, exposure to the electric field did not activate the pacemaker which remained suppressed throughout the exposure routine (Figure 4).

When the pacemaker was made to operate in the asynchronous mode by setting it to rates marginally higher than the natural rate, pacing was occasionally interrupted by the occurrence of ventricular ectopic beats or small increases in the spontaneous cardiac rate. When the hysteresis parameter was set to low value (40 beats/min), the pacemaker was inactivated by these rhythm changes until reset (Figure 5). On no occasion, however, was the pacing function influenced directly by the electric field.

In the single case when the pacemaker was programmed to the triggered (synchronous) mode, the rate of pacemaker discharge was not directly affected by the electric field.

Pacemaker function after exposure: Pacemaker function assessed after exposure to the electric field did not differ from pre-exposure performance. The programmed parameters were never altered by the electric field.

Discussion

The recording of electrocardiographic signals in the presence of a high intensity power frequency electric field is technically difficult because of the gross 50 Hz interference picked up by the electrodes and leads. Careful electrode positioning and electrostatic screening is necessary to reduce such interference to a tolerable level. The use of radio telemetry allows

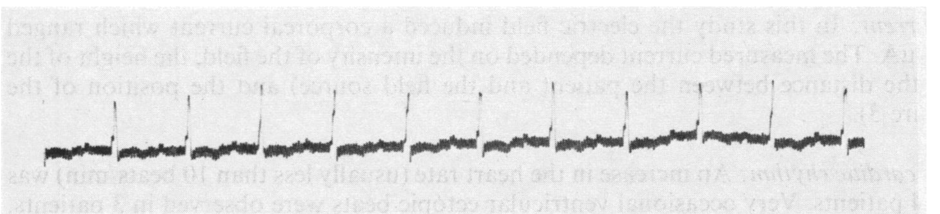

Figure 4. ECG recorded during exposure. The demand pacemaker rate is set at less than the spontaneous heart rate. No pacing artefacts or consequent effects on the cardiac rhythm are induced

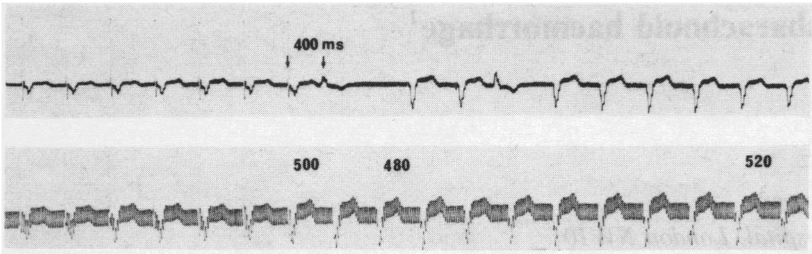

Figure 5. Two examples of electrocardiograms when the pacemaker was set to pace at a rate (120 bpm) faster than the spontaneous heart rate. The escape interval (hysteresis) was set at 1500 msec. In both cases during exposure the pacemaker ceased to pace because of ventricular ectopic beats (top trace) or increase of the natural heart rate

continuous direct monitoring of the cardiac signals and has great practical advantages over tape-recording and subsequent replay (Meldrum *et al.* 1982).

The maximum 50 Hz electric field likely to be encountered by individuals standing directly beneath high-tension power lines is about 10 kV/m and usually such fields are associated with a body current not exceeding 150 μA (Bridges & Frazier 1979). When this current passes through the resistive tissues of the body, potential differences will be generated. Such potentials are more likely to be sensed by pacemakers of so-called unipolar configuration, because of the relatively large vertical electrode separation (between the pacemaker and the electrode tip) (Bridges and Frazier 1979, Zalewski 1975).

It is clear from our results that high-intensity power-frequency electric fields up to 20 kV/m do not interfere with the pacing mode nor with the function of the modern, high-sensitivity, implanted generator chosen for the study. In particular, we did not encounter the reversion to the asynchronous mode observed in earlier laboratory studies (Bridges & Frazier 1979, Smyth *et al.* 1974, Zalewski 1975). This is probably due to a special reversion circuit incorporated in the Medtronic 5985 pacemaker. The circuit adjusts the sensitivity of the sensing amplifier so that regular interfering signals are ignored.

The shut-down of pacemakers in this experiment was entirely due to variations in the rate and rhythm of the heart. Previously published data have suggested that high-intensity power-frequency electric fields do not affect the normal heart rhythm (Hauf 1974) and it is probable that mild anxiety, produced by standing in the unfamiliar surroundings of a high-voltage laboratory, induced the small increase in heart rate and the occasional ectopic beats that were observed.

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